SENSITIVITY OF QUANTITATIVE COMPUTED TOMOGRAPHY (QCT) FOR BONE MINERAL DENSITY (BMD) DETERMINATION

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The sensitivity, precision and accuracy of using quantitative computed tomography (QCT) in determining the extent of bone loss from trabecular region were studied. For a homogenous medium, the accuracy and precision of the measured QCT BMD values deviate less than 3% for aqueous solutions of K₂HPO₄. Whereas in a typical living human lumbar vertebrae, the accuracy of QCT BMD results has to take into account a standard deviation of between 25% to 35% . The quantitated computed tomography sensitivity was unable to differentiate any change in BMD by 2, 4, 6, 8, 10, 20, 40 mg/cm³.

Keywords: Quantitative computed tomography (QCT), trabecular bone, osteoporosis, bone mineral density (BMD)

INTRODUCTION

Osteoporosis is a common cause of vertebral and hip fractures. Studies have shown that the rate of turnover of spinal trabecular bone is 20-25% per year (Frost, 1969) as opposed to the 1 – 3% per year turnover of compact bone. High measurement precision is necessary to provide sensitivity for small mineral changes in serial studies to assess the efficacy of treatment regimes or the progression of disease process. In bone mineral density measurements, it is important to distinguish with certainty between bone loss of 1 – 2% per year. To be able to reliably diagnose a loss of 5% requires a measurement reproducibility of better than 2%. Generally, a change in the patient’s condition can only be assessed with statistical certainty if it exceeds 2.8 times the standard deviation. Bone mineral density (BMD) is an established, important predictor of risk of osteoporotic fracture and has been widely used in the clinical management of osteoporosis. Reproducibility of bone mineral density measurements is of great importance, since it will determine if follow-up controls are meaningful.

MATERIALS AND METHODS

The quantitative computed tomography for bone mineral density was carried out at the University of Malaya Medical Centre using multislice, helical scan computed tomography .

Abdominal phantoms simulating human the torso region were constructed from Dentsply pinnacle hard modeling wax. Concentrations of K₂HPO₄ at 2, 4, 6, 8, 10, 20, 40 mg/cm³ intervals ranging from 200 mg/cm³ down to 160 mg/cm³ were prepared for QCT system sensitivity response between consecutive scans. Concentrations of 0, 50, 100, 200 mg/cm³ were also prepared by using Analar grade anhydrous K₂HPO₄ powder. The known concentrations of K₂HPO₄ were placed in the “spine” region using 50 ml, 3.5 cm diameter latex free syringe.

The CT was calibrated using single energy kvP technique (80 kvP, 80 mA, pitch 3, 5.0 mm slice thickness, using large focal spot size 1.2 mm (w) x 1.2 mm (L) with table height set at 166.5 ± 0.5 cm). Model 2 CT calibration phantom (Mindways, San Francisco, U.S.A) with aqueous solutions of 0, 50, 100 and 200 mg/cm³ K₂HPO₄ and one high density polyethylene material was used for calibration. Model 3 QA torso phantom was used for checking the system’s performance. An anterior posterior (AP) and a scout view are performed before each actual scan of the abdominal phantom.

The CT images from the CT console were transferred to the QCTPRO workstation and translated into a format readable by the QCTPRO software. Region of interest (ROI) was drawn manually in each case. The equivalent amount of K₂HPO₄ within the trabecular bone region were calculated on the basis of the mean CT number within the ROI of the simulated human vertebra.

For the QCT scans of QA torso phantom, Perpex Embedded Spine Skeleton (PESP), Bovine phantom (B1 to B5), Cadaver phantom (cadaverL1, CadaverL2) and volunteers, the subject is positioned supine, with the knees flex (for live subject) so that T11 through L4 will be over the calibration phantom. The QCT BMD scans for all the above phantom variation were repeated on different days and the standard deviation for each of the QCT BMD results were determined.
RESULTS

Table 1 shows the results obtained for known concentrations of K$_2$HPO$_4$ in simulated wax phantom.

<table>
<thead>
<tr>
<th>Actual [K$_2$HPO$_4$] (mg/cm$^3$)</th>
<th>Corrected QCT BMD (mg/cm$^3$)</th>
<th>% deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>161.98</td>
<td>1.24</td>
</tr>
<tr>
<td>170</td>
<td>174.66</td>
<td>2.74</td>
</tr>
<tr>
<td>180</td>
<td>181.34</td>
<td>0.74</td>
</tr>
<tr>
<td>190</td>
<td>190.40</td>
<td>0.21</td>
</tr>
<tr>
<td>192</td>
<td>194.59</td>
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<td>194</td>
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<td>198.68</td>
<td>1.37</td>
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<tr>
<td>198</td>
<td>202.30</td>
<td>2.17</td>
</tr>
<tr>
<td>200</td>
<td>201.05</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Table 1 indicated that after background subtraction, the maximum % error for each known concentrations of K$_2$HPO$_4$ was found to be less than 3%. Repeatability of each known concentrations of K$_2$HPO$_4$ was found to be less than 1 % coefficient of variation in agreement with the claim made by the manufacturer of QCT PRO.

Results of Table 1 and Figure 1 do not indicate QCT is capable providing a confirmation that there is any change of BMD between any consecutive scans which differs by 2mg/cm$^3$, 4 mg/cm$^3$, 6mg/cm$^3$, 8mg/cm$^3$, but for the measured QCT BMD which differs greater than 10mg/cm$^3$, 20mg/cm$^3$, 30mg/cm$^3$, 40mg/cm$^3$ or greater. The change in the QCT BMD is more significant as the percentage standard deviation is less than 3 %.

![Sensitivity of QCT in detecting change in K2HPO4 (BMD)](image)

Figure 1. Sensitivity of QCT in detecting changes in K$_2$HPO$_4$ (“BMD”) of the QA Torso phantom at the concentration of 250 mg/cm$^3$. Figure 3 and Figure 4 shows the QCT BMD standard variation for each type phantom over a period of time.

![Reproducibility of QCT BMD for various spine phantoms over a period of time (80 kV, 80 mA, 5mm slice thickness)](image)

Fig. 2 – Reproducibility of QCT BMD for various spine phantoms (QA Torso Phantom, Perspex Embedded Skeleton Phantom (PESP), bovine phantom (B1-B5), Cadaver phantom (Cadaver L1, Cadaver L2) and patients.)
QCT BMD Standard deviation (SD) for various phantom with time

Fig. 3 – QCT BMD Standard deviation for various phantoms with time

QA Torso phantom
Perspex Embedded Skeleton Phantom (PESP)
B1
B2
B3
B4
B5
cadaver L1

% Standard Deviation (%SD) of various phantoms with time

Fig. 4 – % standard deviation of various phantoms with time.

Discussions

Results of Table 1 and Figure 1 do not indicate that QCT is capable of providing a confirmation that there is any change of BMD between any consecutive scans which differs by 2mg/cm³, 4mg/cm³, 6mg/cm³, 8mg/cm³. For changes in measured QCT BMD which differs by greater than 10mg/cm³, 20mg/cm³, 30mg/cm³, 40mg/cm³ or greater, the measured results do provide an indication of such changes. The small changes were non-confirmative of such changes due to the fact that the percentage standard deviation can vary from 0.21 to 2.74 (Table 1) and the measure QCT BMD for a particular concentration can deviate from the actual concentration up to 5mg/cm³.

The measured QCT BMD for the QA torso phantom at 250 mg/cm³ were quite stable as shown in Figure 2. Whereas the measured QCT BMD for live patient were around 100 mg/cm³. The mean value of Cadaver L1 and Cadaver L2 were also around 100 mg/cm³. That of cadaver L1 were of lower value possibly some of the bone minerals might have leached out over a period of time as the vertebra used has been kept preserved before used. Those of skeleton phantom PESP were also around 100 mg/cm³. The values for the bovine phantom B1, B2, B4 were greater than 300 mg/cm³ and those of B3, B5 range from 70 mg/cm³ to 150 mg/cm³, due to the fact that various section of the bovine have been used and there are variability between different sections of the vertebra used.

Figure 3 shows that the QA torso phantom QCT SD were around 10 mg/cm³ and did not vary much over a period of time. The live patient’s was typically around 25 to 35 mg/cm³. Those of bovine phantom can vary up to 120 mg/cm³, possibly due to the presence of air spaces in the cut out bovine vertebra. That of the cadaver can vary by 30 mg/cm³, possibly variability in the region of vertebra scan each time and much differences in the vertebra itself as some part of the bone has been leached out.
CONCLUSION
The technique has not shown that it can be used to detect changes in bone mineral content of less than 10 mg/cm². A reproducibility of 3% of BMD measured by QCT applies to a homogenous medium only. Bone is a non-homogenous medium, there is considerable spatial variation in the amount of bone tissue within the trabecular space, which unless recognized may interfere with the reproducibility of the technique. Hence, clinical use of QCT for BMD has to include a standard deviation of 25-35% in the final QCT BMD reported results. At the current status, QCT is recommended for detecting changes in BMD only, not for monitoring response to treatment as it cannot offer such sensitivity when the changes is less than 10 mg/cm².

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REFERENCES